

Urinary *chiro*-Inositol Excretion is an Index Marker of Insulin Sensitivity in Japanese Type II Diabetes

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OBJECTIVE — To determine the relationship between urinary *chiro*-inositol excretion and insulin sensitivity in Japanese type II diabetic patients.

RESEARCH DESIGN AND METHODS — Eighteen subjects were age-matched, nonobese, type II diabetic patients. Eight subjects had impaired glucose tolerance (IGT), and 10 had normal glucose tolerance (NGT). We quantified urinary *chiro*-inositol excretion using gas chromatography-mass spectrometry and the insulin sensitivity index (S_I), and glucose effectiveness (S_G) using Bergman's modified minimal model method.

RESULTS — The urinary excretion of *chiro*-inositol was much lower in the diabetic patients (32.3 ± 16.0 $\mu\text{mol/day}$, means \pm SD) than in the NGT subjects (96.0 ± 17.6 ; $P < 0.0001$) and IGT subjects (58.9 ± 11.6 ; $P < 0.0001$). S_I was much lower in the diabetic patients (3.81 ± 1.49) than in the NGT subjects (6.30 ± 1.59 , $P < 0.0005$). S_G was much lower in the diabetic patients (2.14 ± 0.56) than in the NGT subjects (3.07 ± 0.38 , $P < 0.0001$). There was a significant correlation between urinary *chiro*-inositol excretion and S_I ($r = 0.766$), as well as a significant correlation between urinary *chiro*-inositol excretion and S_G ($r = 0.747$).

CONCLUSIONS — There is a direct relationship of urinary *chiro*-inositol excretion to insulin sensitivity and S_G in humans. Urinary *chiro*-inositol excretion might be useful as a metabolic index of insulin sensitivity in type II diabetes.

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NGT, normal glucose tolerance; IGT, impaired glucose tolerance; S_I , insulin sensitivity index; S_G , glucose effectiveness; BMI, body mass index.

The molecular mechanism of insulin resistance in type II diabetes is not well known. Insulin binding to its receptor induces hydrolysis of phosphatidylinositol-glycan and releases inositol-glycan and diacylglycerol, two putative second messengers of insulin actions (1-3). *Chiro*- and *myo*-inositols are major components of the inositol-glycans and phosphatidylinositol-glycans (4-7). Kennington et al. (5) reported hypochiro-inositoluria in type II diabetic subjects and decreased *chiro*-inositol in mediator prepared from skeletal muscle biopsies of Pima Indian diabetic subjects together with increased urinary *myo*-inositol excretion. Ortmeyer et al. (6) demonstrated a direct relationship of insulin resistance, as measured by five parameters of insulin action to urinary *chiro*-inositol excretion in the type II diabetic rhesus monkey (*Macaca mulatta*). Nonobese type II diabetic GK (Goto-Kakizaki) rats have been shown to manifest insulin resistance, decreased insulin action, and strikingly decreased urine *chiro*-inositol together with increased urine *myo*-inositol (7). We investigated the possible linkage of hypochiro-inositoluria to insulin resistance in Japanese type II diabetic patients.

RESEARCH DESIGN AND METHODS

The study protocol was approved by the Tohoku University Institutional Review Board. Informed consent was obtained from each subject. The subjects were age-matched, nonobese, subjects with normal glucose tolerance (NGT) ($n = 10$), subjects with impaired glucose tolerance (IGT) ($n = 8$), and type II diabetic patients ($n = 18$), as shown in Table 1. All subjects were free of hypertension, hyperlipidemia, and ischemic cardiovascular diseases and had normal 24-h creatinine clearance. All diabetic patients, IGT subjects, and NGT subjects fulfilled the World Health Organization criteria for diabetes. IGT and NGT subjects were evaluated within a year by 75 g oral glucose tolerance tests (8). All diabetic patients were classified as having type II

Urinary chiro-inositol excretion in type II diabetes

Table 1—Clinical characteristics, S_I , S_G , and 24-h urinary excretion of chiro-inositol and myo-inositol in study subjects

Subjects	NGT	IGT	Diabetes
n	10	8	18
Sex (M/F)	5/5	4/4	10/8
Age (years)	51.0 ± 17.0	52.2 ± 13.2	55.9 ± 10.2
BMI	21.1 ± 1.2	22.0 ± 1.2	22.4 ± 1.4
Plasma C-peptide after glucagon (ng/ml)	6.66 ± 2.66	5.61 ± 2.77	4.42 ± 1.60*
Urinary C-peptide excretion (ng/day)	102.6 ± 31.2	86.6 ± 32.6	70.4 ± 19.9†
S_I ($\times 10^{-4} \cdot \text{min}^{-1} \cdot \mu\text{U}^{-1} \cdot \text{ml}^{-1}$)	6.30 ± 1.59	4.80 ± 0.58†	3.81 ± 1.49§
S_G ($\times 10^{-2} \text{ min}$)	3.07 ± 0.38	2.55 ± 0.50	2.14 ± 0.56¶
Urinary chiro-inositol excretion ($\mu\text{mol/day}$)	96.0 ± 17.6	58.9 ± 11.6#	32.3 ± 16.0 ^{a,b}
Urinary myo-inositol excretion ($\mu\text{mol/day}$)	192 ± 54	212 ± 55	499 ± 112 ^{c,d}

Data are means ± SD. * $P < 0.01$ (NGT vs. diabetes). † $P < 0.005$ (NGT vs. diabetes). ‡ $P < 0.05$ (NGT vs. IGT). § $P < 0.0005$ (NGT vs. diabetes). || $P < 0.05$ (NGT vs. IGT). ¶ $P < 0.0001$ (NGT vs. DM). # $P < 0.0002$ (NGT vs. IGT). ^a $P < 0.0001$ (NGT vs. diabetes). ^b $P < 0.0005$ (IGT vs. diabetes). ^c $P < 0.0001$ (NGT vs. DM). ^d $P < 0.0001$ (IGT vs. diabetes).

diabetes because their plasma C-peptide level 6 min after a 1 mg glucagon injection was >2 ng/ml (4.42 ± 1.60 ng/ml), as well as their urinary C-peptide excretion for 24 h was >40 ng/day (70.4 ± 19.9 ng/day) as shown in Table 1. Diabetic patients were free of ketoacidosis episodes and diabetic complications except for minimal background retinopathies. Diabetic patients were treated with diet therapy ($n = 8$) or oral hypoglycemic agents ($n = 10$) and were under stable control, as means ± SD HbA_{1c} concentrations in the diabetic patients were $6.51 \pm 0.62\%$.

Gas chromatography-mass spectrometry determination of 24-h chiro-inositol excretion

We collected urine samples for 24 h, which were frozen until processed for analysis. Aliquots (5 ml) were passed through 1-ml mixed bed ion-exchange resins (Amberlite MB-3) to remove ionic substances and then through a C₁₈ Sep-Pak cartridges (Waters) to remove nitrogenous, hydrophobic, or peptide-like materials. The inositols and other neutral hydrophilic materials were eluted from the Sep-Pak cartridges with 2 ml water and lyophilized. The lyophilized samples were derivatized with 100 μl of heptafluorobutyrylimidazole (Pierce) and heated at 55°C for 5 h. The samples were then extracted into 200 μl n-hexane and sub-

jected to gas chromatography-mass spectrometry analysis, as described by Kennington et al. (5). All samples were analyzed twice, and the results reported are the average of the two analyses (rate of error $<6\%$).

Minimal model study

The insulin sensitivity index (S_I) and glucose effectiveness (S_G) were assessed by the use of the modified Bergman's minimal model method with an additional administration of insulin 20 min after the glucose bolus (0.3 g/kg), as described by Welch et al. (9). The NGT, IGT, and diabetic subjects received 0.02 U/kg regular human insulin. Plasma glucose was assayed using the glucose oxidase method. Plasma insulin and C-peptide were assayed using radioimmunoassay kits.

Statistical analysis

Data are expressed as means ± SD. Statistical analysis was made by means of the unpaired Student's *t* test. $P < 0.05$ was considered statistically significant.

RESULTS—The urinary excretion of chiro-inositol was much lower in the type II diabetic patients (32.3 ± 16.0 $\mu\text{mol/day}$) than in the NGT (96.0 ± 17.6 ; $P < 0.0001$) and IGT subjects (58.9 ± 11.6 ; $P < 0.0005$), as shown in Table 1. The urinary chiro-inositol excretion was much

lower in the IGT subjects than in the NGT subjects ($P < 0.0002$). The mean urinary myo-inositol excretion was higher in the diabetic patients (499 ± 112 $\mu\text{mol/day}$; $P < 0.0001$) than in the IGT subjects (212 ± 55) and NGT subjects (192 ± 54) (Table 1). S_I in the NGT, IGT, and diabetic subjects were 6.30 ± 1.59 , 4.80 ± 0.58 , and $3.81 \pm 1.49 \times 10^{-4} \text{ min}^{-1} \cdot \mu\text{U}^{-1} \cdot \text{ml}^{-1}$, respectively (Table 1). S_I was much lower in the diabetic patients than in the NGT subjects ($P < 0.0005$). S_I was also lower in the IGT subjects than in the NGT subjects ($P < 0.05$). There was a significant correlation between urinary chiro-inositol excretion and S_I ($r = 0.766$), as shown in Fig. 1. S_G in the NGT, IGT, and diabetic subjects were 3.07 ± 0.38 , 2.55 ± 0.50 , and $2.14 \pm 0.56 \times$

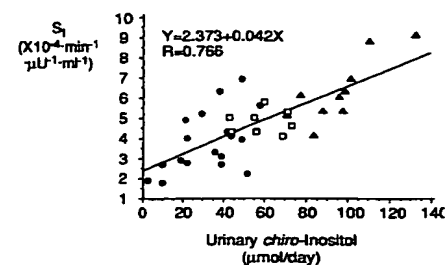


Figure 1—Relationship between urinary excretion of chiro-inositol for 24 h and S_I . ●, type II diabetic patients; □, IGT subjects; ▲, NGT subjects.

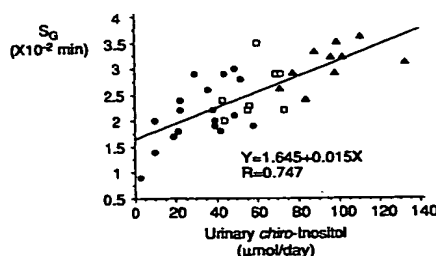


Figure 2—Relationship between urinary excretion of chiro-inositol for 24 h and S_G . ●, type II diabetic patients; □, IGT subjects; ▲, NGT subjects.

10^{-2} min, respectively (Table 1). S_G was lower in the diabetic patients than in the NGT subjects ($P < 0.0001$). S_G was also lower in the IGT subjects than in the NGT subjects ($P < 0.05$). There was also a significant correlation between urinary chiro-inositol excretion and S_G ($r = 0.747$), as shown in Fig. 2. There was no correlation between urinary chiro-inositol excretion and the age, sex, and body mass index (BMI) of three groups (data not shown). There was a weak correlation between urinary chiro-inositol excretion and plasma C-peptide concentrations 6 min after glucagon injection ($r = 0.581$) (data not shown). There was a significant correlation between plasma C-peptide concentrations 6 min after glucagon injection and 24-h urinary C-peptide excretion ($r = 0.681$); however, there were no correlation between urinary chiro-inositol excretion and 24-h urinary C-peptide excretion (data not shown). There was no significant correlation between urinary chiro-inositol and myo-inositol excretion (data not shown).

CONCLUSIONS—Peripheral insulin resistance of glucose metabolism in type II diabetes has been characterized as postreceptor, predominantly in nonoxidative glucose metabolism, directly correlated with a decreased ability of in vivo insulin to activate muscle glycogen synthase, and yielding a decreased glucose metabolism rate (10,11). The fact that de-

creased muscle glycogen synthase activation has been observed in first-degree relatives who are not diabetic suggests a familial or possibly genetic basis for the resistance (10,11). Bergman's modified minimal model method using exogenous insulin has been applied to estimate simultaneously S_1 and S_G in normal subjects and type II diabetic patients (9,12–14). Values of S_1 obtained by the modified minimal model method were highly correlated with the S_1 measured using the euglycemic glucose clamp method (12). S_G , the ability of glucose per se, independent of changes in insulin, to increase glucose uptake and suppress endogenous output, is commonly reduced in type II diabetes (12). The defects in S_1 and S_G are synergistic in causing glucose intolerance in type II diabetic and IGT subjects (12).

This study demonstrates a significant correlation between urinary chiro-inositol excretion and S_1 , as well as S_G , and a weak correlation between urinary chiro-inositol excretion and plasma C-peptide concentrations 6 min after glucagon injection, but no significant correlation between urinary chiro-inositol excretion and 24-h urinary C-peptide excretion. These data suggest a causal relationship between urinary chiro-inositol excretion and in vivo insulin resistance. A significant correlation between urinary chiro-inositol excretion and in vivo insulin resistance was reported in type II diabetic rhesus monkeys (5). Hypochiro-inositoluria and insulin resistance were also demonstrated in GK rats (7). Asplin et al. (15) documented decreased inositol-glycan bioactivity and chiro-inositol content in the inositol-glycan fractions isolated from hemodialysate, urine, and autopsy muscle of type II diabetic subjects. In contrast, the myo-inositol-containing inositol-glycan activities from the three sources were indistinguishable when nondiabetic and type II diabetic subjects were compared (12). Ortmeier et al. (16) demonstrated acute hypoglycemic effects of oral D-chiro-inositol administration in streptozotocin-induced diabetic rats and diabetic rhesus monkeys

(16). We recently found that oral administration of D-chiro-inositol for a month normalized the deficiency of chiro-inositol in skeletal muscle and liver of the diabetic GK rats and improved glucose intolerance in the rats, insulin sensitivity on glycogen synthesis, lipogenesis, and activation of pyruvate dehydrogenase in rat-isolated adipocytes (17). These studies provide evidence that chiro-inositol deficiency may be linked to peripheral insulin resistance in type II diabetes. Pak et al. (19) have demonstrated a pathway of chiro-inositol biosynthesis from myo-inositol in rats (18) and rat fibroblasts, which are stimulated by insulin. Nothing is known about the formation of chiro-inositol in humans. Defects of chiro-inositol biosynthesis or metabolism might contribute to insulin resistance, a key important early manifestation of type II diabetes. Low urinary excretion of chiro-inositol might be useful for evaluation of insulin resistance and impaired glucose utilization in type II diabetes.

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